

Nuclear diagnostics and Magnetic Resonance Imaging

Week 1; Lecture 2; Section 2: Methods for production of radionuclides

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Section 2

Methods for the production of radionuclides

Methods for the production of radionuclides; overview

Nuclear reactor:

- Neutron capture
- Fission fragments

Radionuclide generators:

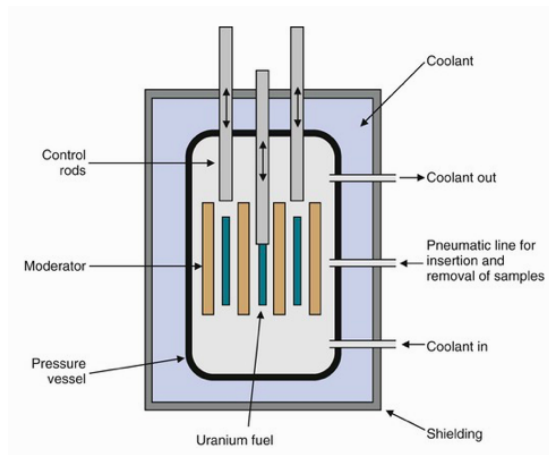
- Portable devices widely used in hospitals
- Require materials produced in nuclear reactors or accelerators

Accelerator:

- Cyclotron
- Active area of research:
 - Related areas of research within the CCAP

Nuclear reactor; one-slide outline

- Graphite or D_2O moderator surrounds fissionable fuel cells
- Control rods, commonly boron, shield or expose fuel cells
- Position of fuel cells & control rods determine rate of chain reaction
- Ports in core allow insertion of samples for irradiation



Used to generate fission products or perform neutron activation

Nuclear reactor: radionuclides produced by 'neutron activation'

Fission of ^{235}U produces neutrons which bombard samples introduced into the core.

Neutron activation produces:

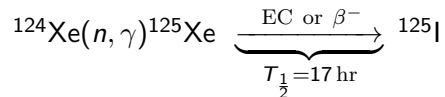
- Neutron-rich radionuclides, which usually undergo beta decay
- Product is chemically identical to parent material:
 - Product therefore can not be separately chemically;
 - Results in lower purity and lower activity than other production methods

Example reactions:

- $^{31}\text{P}(n, \gamma)^{32}\text{P}$
 - Capture of n produces $^{32}\text{P}^*$ which decays to ^{32}P emitting a γ
- $^{50}\text{Cr}(n, \gamma)^{51}\text{Cr}$

Nuclear reactor: production of ^{125}I

^{125}I is produced via neutron activation and *can* be chemically separated, vis:

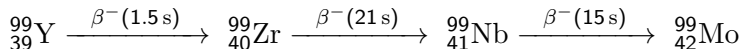


Nuclear reactor: production via fission fragments

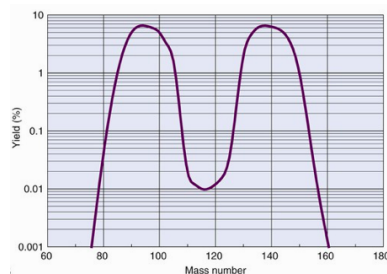
Fission fragments:

- Have bimodal distribution in A
- Excess of neutrons, hence tend to undergo β^- decay until stable nucleus is produced

If long-lived isotope is produced it can be chemically extracted, e.g.:



Half-life of ${}^{99}\text{Mo}$ is 65.9 hr, long enough to allow it to be extracted and incorporated in radionuclide generator to produce ${}^{99\text{m}}\text{Tc}$



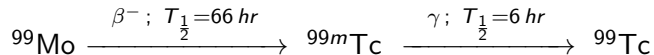
Radionuclide generators

Parent-daughter radionuclide pair in an apparatus that permits separation and extraction of the daughter from the parent

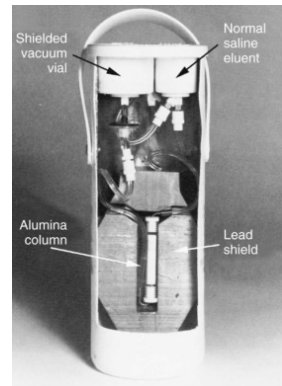
$T_P > T_D$ so that daughter product is replenished continuously by the decay of the parent and may be extracted repeatedly

Provides a local supply of short-lived radionuclides without needing a cyclotron or nuclear reactor

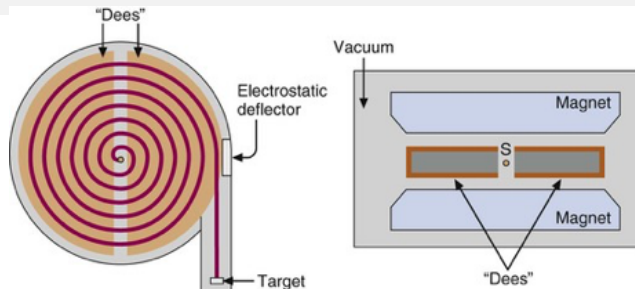
Radionuclide generator: ^{99m}Tc for imaging



- ^{99}Mo bound to an alumina column in form of molybdate ion (MoO_4^-)
- ^{99m}Tc , the decay product, is not bound to column; it is chemically different
- ^{99m}Tc is eluted from column with 5–25 ml saline
- 75–85% of available ^{99m}Tc can be extracted
- Typically used for one week
- Often referred as a 'Molly' or a 'Cow'



Accelerator: cyclotron



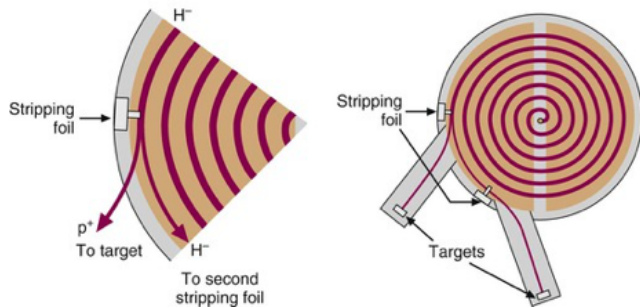
Cyclotron frequency, f :

$$f = \frac{qB}{2\pi m}$$

where q is ion charge, B the magnetic field strength, and m is ion mass.

Extraction is at a single, pre-determined, energy.

Accelerator: cyclotron



Schematic of H^- ion cyclotron showing stripping foils and targets.

Compact biomedical cyclotron



Medical cyclotrons often located near PET scanner due to short lifetimes of radionuclides that are produced.

Examples of cyclotron-produced radionuclides

Product	Decay Mode	Common Production Reaction	Natural Abundance of Target Isotope* (%)	Energy Threshold (MeV)*
^{11}C	β^+ , EC	$^{14}\text{N}(\text{p},\alpha)^{11}\text{C}$	99.6	3.1
		$^{10}\text{B}(\text{d},\text{n})^{11}\text{C}$	19.9	0
^{13}N	β^+	$^{16}\text{O}(\text{p},\alpha)^{13}\text{N}$	99.8	5.5
		$^{12}\text{C}(\text{d},\text{n})^{13}\text{N}$	98.9	0.35
^{15}O	β^+	$^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$	99.6	0
		$^{15}\text{N}(\text{p},\text{n})^{15}\text{O}$	0.37	—
^{18}F	β^+ , EC	$^{18}\text{O}(\text{p},\text{n})^{18}\text{F}$	0.20	2.57
		$^{20}\text{Ne}(\text{d},\alpha)^{18}\text{F}$	90.5	0
^{67}Ga	(EC, γ)	$^{68}\text{Zn}(\text{p},2\text{n})^{67}\text{Ga}$	18.8	5.96
^{111}In	(EC, γ)	$^{109}\text{Ag}(\alpha,2\text{n})^{111}\text{In}$	48.2	—
		$^{111}\text{Cd}(\text{p},\text{n})^{111}\text{In}$	12.8	—
^{123}I	(EC, γ)	$^{122}\text{Te}(\text{d},\text{n})^{123}\text{I}$	2.6	—
		$^{124}\text{Te}(\text{p},3\text{n})^{123}\text{I}$	4.8	—
^{201}Tl	(EC, γ)	$^{201}\text{Hg}(\text{d},2\text{n})^{201}\text{Tl}$	13.2	—

Radioisotopes produced using cyclotron beams.
Decay schemes and production reactions are given.

Summary of section 2

Production methods:

- Nuclear reactor
- Radionuclide generators, e.g. “molly cow”
- Accelerator